Concepts of Event Reconstruction

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August 3, 2007

Directly Detectable Particles

- electrons, positrons: $e^{\pm}$, lightest charged lepton
- photons: γ, gauge boson for electromagnetic force
- pions: $\pi^{\pm}$, lightest mesons
- kaons: $K^{\pm}$, K_L, lightest strange mesons
- protons: p, lightest charged baryon
- neutrons: n, lightest baryon
- nuclei: He, C, PB, *etc.*

Detectable because relatively long-lived, something inhibits decay in each case.

Particle Properties

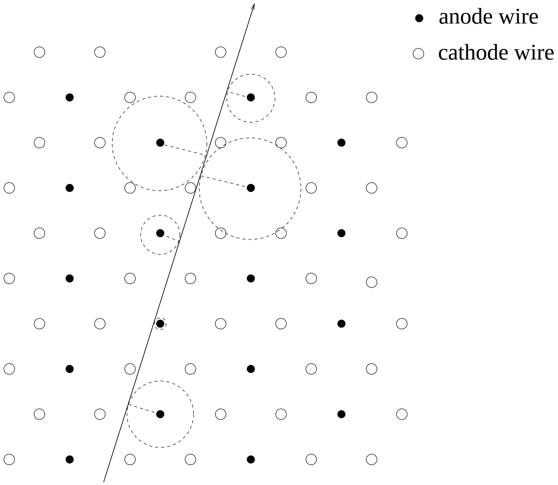
- charged/neutral: feel EM force?
- strongly interacting: hadrons, *e. g.*, mesons, baryons, pentaquarks
- massive/massless
- showering (electromagnetic or hadronic): energy $>>$ mass, significant interaction cross-section
- four-momentum: E, $\vec{p}$
- polarization/spin

Particle Detectors

Detector	Enabling Property	Measured Property
Drift Chambers	charged	position
Time-of-Flight Counters	charged	transit time
Shower Counters	showering	energy
Cerenkov Counters	charged	velocity

Drift Chambers

- Charged particles only
- Measurement of drift time
  - Time-to-digital converter (TDC) for time measurement
  - Time of first detected ionization used
  - Convert to a drift distance
    - known distance-to-time relation
    - drift velocity ≈ 5 cm$/\mu$s
  - Position measurement in one dimension
    - $\perp$ to wire $\Leftarrow$ electron drift direction
    - $\perp$ to particle trajectory $\Leftarrow$ point of closet approach detected


• anode wire
○ cathode wire

- With magnetic field get momentum
  - Lorentz force

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

    where $\vec{F}$ is force, q is charge, $\vec{E}$ is electric field, $\vec{v}$ is velocity, $\vec{B}$ is magnetic field, SI units
  - magnetic bending does no work: no energy loss
  - radius of curvature proportional to momentum

$$p_\perp = (0.3)BR$$

    where $p_\perp$ is momentum transverse to field, B is magnetic field in Tesla, R is radius of curvature in meters
  - only get component of momentum transverse to field

- Turn into a trajectory
  - Trial trajectory, with parameters
    - Field-free: straight line
    - Uniform magnetic field: helix
    - Non-uniform magnetic field: launch parameters, then solve differential equation (numerically)
  - In a magnetic field: 5 parameters
    - 3 components of momentum: p_x, p_y, p_z
    - 2 coordinates of "origin": "x_0", "y_0"
  - Least-squares fit
    - vary parameters, get different trajectories
    - minimize
$$\chi^2 = \sum_i \left(\frac{x_{\mathrm{meas},i} - x_{\mathrm{traj},i}}{\sigma_i} \right)^2$$
    - errors from known measurement error of chamber

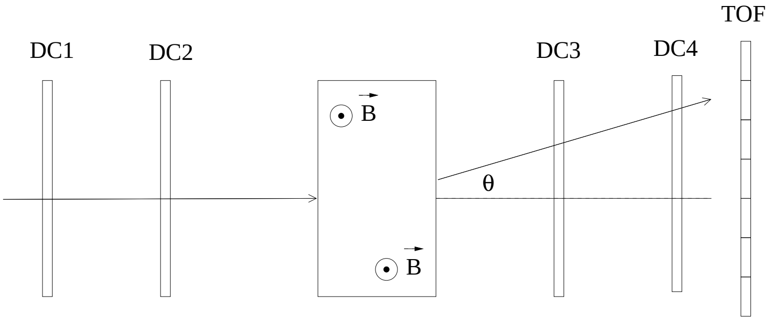
- Error from multiple Coulomb scattering
  - elastic scattering from Coulomb field of atomic nuclei
  - little loss of energy
  - many small changes of direction
  - Kalman filter: weight hits in presence of correlation
- Error from energy loss
  - inelastic scattering from atomic electrons
  - correction requires good knowledge of configuration of material
  - introduces significant complication in algorithm
  - largest corrections often come from material in front of chamber

- Dipole magnet example
  - small angle approximation
  - p_t kick (momentum transverse to field direction)

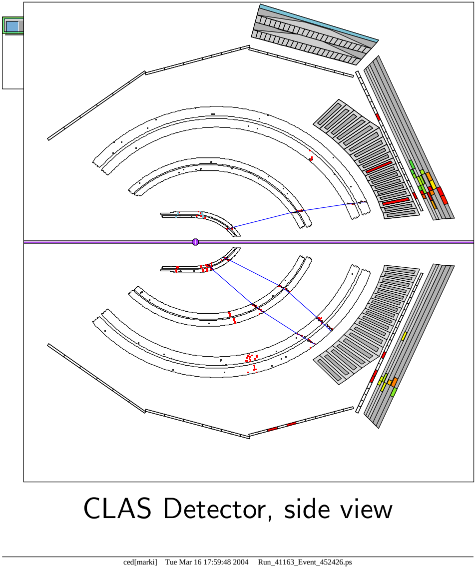
$$\Delta p_t = (0.3)Bl$$

    where l is distance traveled in field, independent of momentum
  - $\theta \approx \Delta p_t / p_t$
  - resolution in momentum:

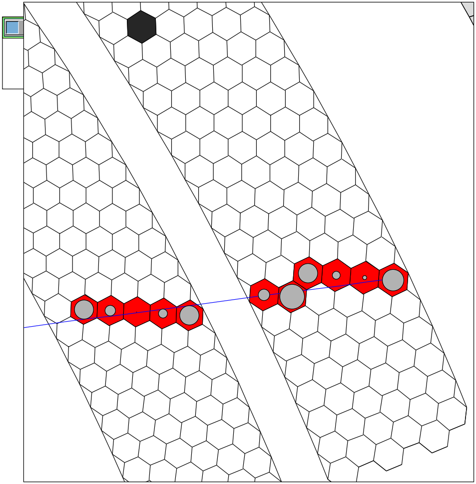
$$\frac{\sigma_{p_t}}{p_t} \propto \frac{p_t \sigma_x}{Bl}$$



Dipole spectrometer



CLAS Detector, side view



Region 3 Drift Chambers, axial and stereo superlayers

ced[marki] Wed Mar 17 07:50:54 2004 Run_41163_Event_452426.ps

Time-of-Flight Counters

- Charged particles (usually)
- Measures "end" of propagation time
- Gives velocity if start time and trajectory is known
- Gives mass if momentum is known as well

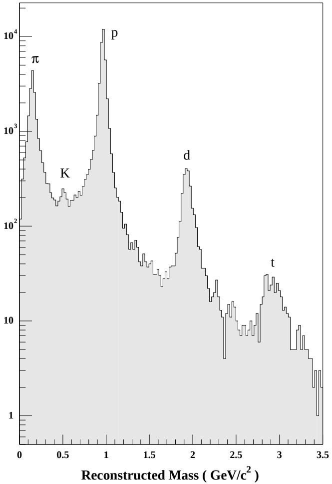
$$p = \gamma\beta mc$$

$$\gamma = \sqrt{\frac{1}{1-\beta^2}}$$

$$\beta = \frac{v}{c}$$

where m is the rest mass of the particle

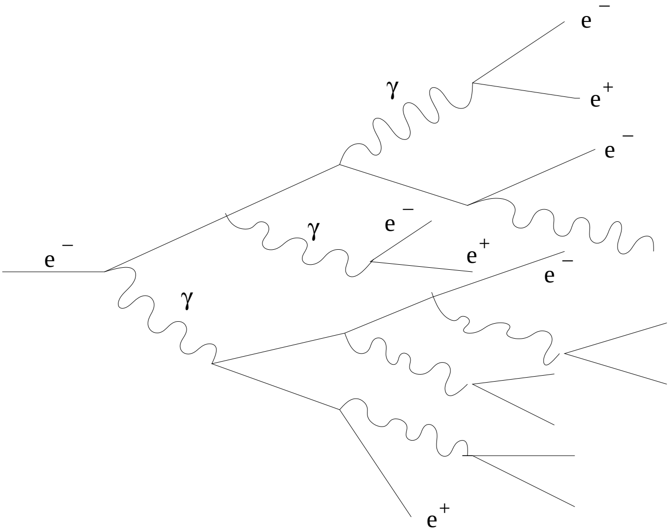
- E. g., pion vs. kaon
  - $m_{\pi^+} = 140\ \mathrm{MeV}/c^2$
  - $m_{K^+} = 494\ \mathrm{MeV}/c^2$



CLAS drift chamber and time-of-flight particle identification

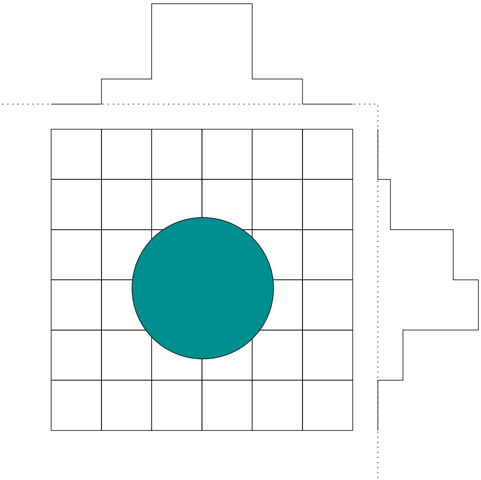
Shower Counters

- Electromagnetic shower
  - electrons and positrons bremsstrahlung photons
    - nuclear Coulomb field
  - photons produce electron positron pairs
    - nuclear Coulomb field
  - cascade, tree-like effect
  - length scale set by material's radiation length, X_0
- Hadronic shower
  - hadrons interact producing hadrons
  - nuclear strong interaction
  - length scale set by material's interaction length, λ_I



Electromagnetic shower

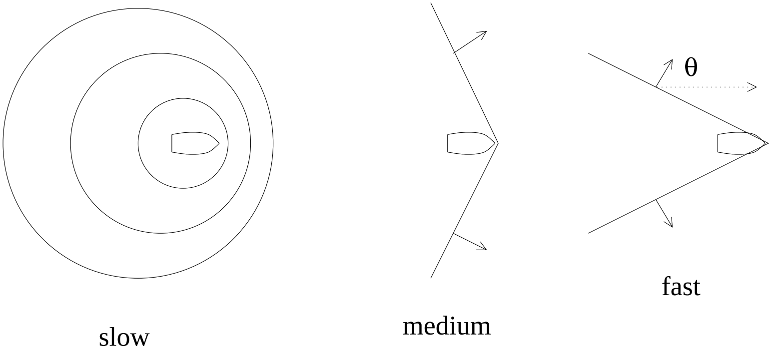
- Shower properties
  - Charged particles create a signal
  - Exponential increase in number of particles initially
  - Shower dies as particles lose energy
  - Most of charged particles created "deep" into shower
- Energy measurement
  - Sum signals from all charged particles (E&M: $e^{\pm}$) in shower
  - Sum proportional to energy of original particle
    - $E_{\mathrm{incident}} \propto N_{e^{\pm}}$
    - $\mathrm{Signal} \propto N_{e^{\pm}}$
    - resolution $\sigma_E \propto \sqrt{E}$
- Position measurement
  - Detector position known
  - If signal shared between adjacent modules
    - Compare relative signal
    - Interpolate position



Position determination for a shower counter

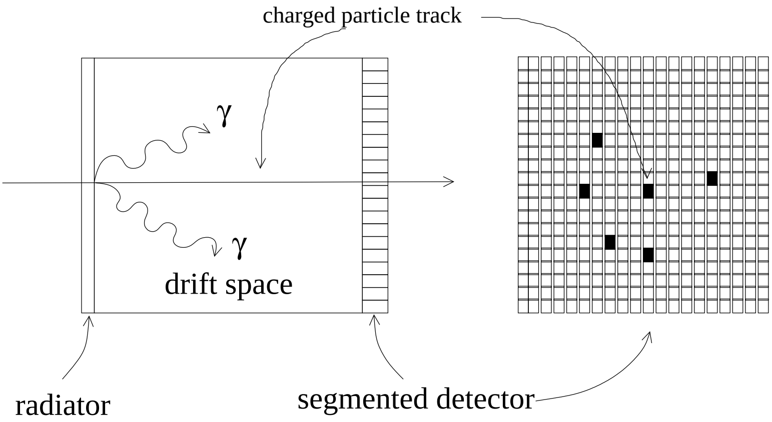
Cerenkov Counters

- Principle of operation
  - Light emitted when charged particle moves faster than speed of light in a medium.
    $$v > \frac{c}{n}$$
    where c is speed of light, n is index of refraction in medium
  - Light emitted at a characteristic angle from trajectory
    $$\theta_C = \arccos \frac{c}{nv}$$
    where θ_C is the half-angle of cone of emission (Cerenkov angle)



Bow waves and the Cerenkov angle

- Threshold
  - Fast? Yes or no answer.
  - *E. g.*, electron vs. pion
- Differential
  - Given trajectory, measure angle
  - Gives velocity, quantitatively



Ring-imaging Cerenkov counter

Summary: Correlating the Detectors

	Drift Chamb.	TOF	Shower Cntr.	Cerenkov
electrons	$\vec{p}$, $\vec{r}$		E, $\vec{r}$	
photons			E, $\vec{r}$	
pions	$\vec{p}$, $\vec{r}$	ID		ID
kaons	$\vec{p}$, $\vec{r}$	ID		ID
protons	$\vec{p}$, $\vec{r}$	ID		ID
neutrons		ID	$\vec{r}$	

Multiple detector elements are used in concert to identify particles and measure their kinematic properties.